*International Journal of Advanced Information in Engineering Technology (IJAIET) ISSN:* 2454-6933
*Vol.3, No.8, August 2016*

# Fault Detection and Localization Using Travelling Waves

Gemini George
Electrical & Electronics Department
Saintgits college of Engineering
Kottayam ,India.

Daru Anna Thomas
Assistant professor
Electrical & Electronics Department
Saintgits college of Engineering
Kottayam, India

***Abstract---*** **A new travelling wave based directional protection technique is used in this paper. An extra high speed busbar protection is achieved by this technique. Within a short period of fault occurrence, positive and negative direction travelling waves are extracted, respectively and the corresponding ratio is calculated. This obtained ratio is then compared with a set threshold value. If the ratio value is less than this threshold, the fault direction is thought as positive; otherwise, the fault direction is negative. To evaluate the proposed technique, a typical busbar model was built in PSCAD/EMTDC and the proposed method is verified.**

***Keywords--- Directional travelling wave, Fault location, Transient detection***

## I. INTRODUCTION

THE exact fault location in real power grid is a problem that has been studied over decades. Fast detecting, isolating, locating and repairing of these faults are critical in maintaining a reliable power system operation. The theory of travelling waves has been recently introduced for this purpose. Such methods are based on the theory that considerable change of voltage at the fault point results in transient waves that propagate along the transmission line, with a velocity close to that of light. These fault generated transient components contain a great deal of information such as fault type, time, direction. If these fault generated transients can be precisely extracted, extra high speed busbar protection will be achieved

Until now, the principles of busbar protection can be classified into two types based on power frequency components and transient components. Conventional system protection that includes overcurrent or distance systems, will be applied only to relatively simple distribution systems[1]. in [2] a fault detection algorithm based on the positive and negative sequence models of the power system is used. A novel technique that distinguishes faults in a busbar protection zone, from outside zone is introduced in [3], which works on the concept of directionality. A different approach to directional protection, based on the wavelet transform of fault transients is presented in [4].

A novel travelling wave based ultra high speed directional protection was presented in [9]. Simulation results demonstrated that the proposed technique is unaffected by fault position, fault resistance, and fault type. Referring to the aforementioned method, this paper proposes a travelling wave fault position, fault resistance, and fault type. Referring to the aforementioned method, this paper proposes a travelling wave based directional busbar protection technique. A very simple method using Park's Transformation is used to perform the transient detection. The main idea can be described as follows. When a fault occurs on a busbar, the direction of detected initial travelling waves on all lines connected to this busbar is positive. If the fault occurred is in any of the transmission lines, the direction of detected initial travelling wave on healthy lines is positive, but that on the faulted line is negative. During a very short period of postfault, a busbar fault or line fault can be fast identified according to the amplitude integral relationships between positive travelling wave and negative travelling wave. Feasibility of the presented technique is verified by building a 230kV busbar test system in PSCAD/EMTDC.

## II. WORKING PRINCIPLE

### *A. Theory of Travelling wave propagation*

A simple busbar configuration is shown in Figure 1, where lines $l_1$, $l_2$ and $l_3$ are connected to busbar B, and $R_1$, $R_2$ and $R_3$ denotes the respective relay of lines.

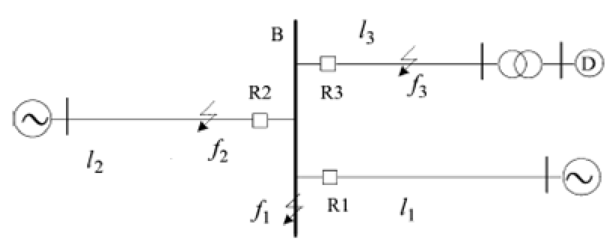



Fig. 1: Model of a Busbar Structure

In Fig. 1, when a fault occurs on the line, the travelling waves generated by this fault will propagate to both ends from the fault point along this line. The reflection and refraction of travelling waves will appear at these points, where wave impedances are discontinuous, such as fault point and busbar.

According to the telegraph equations, if $R_1$ is assumed as the zero reference point, for any position, the transient voltage and current are as follows:

$$\Delta u = u^{+}\left(t-\frac{x}{v}\right)+u^{-}(t+\frac{x}{v}) \quad .......(1)$$

$$\Delta i = \frac{1}{z_c}[\ u^{+}\left(t-\frac{x}{v}\right)+u^{-}(t+\frac{x}{v})] \quad ......(2)$$

$u^{+}$ and $u^{-}$ are the forward travelling wave along the positive direction and backward travelling wave along the negative direction of the line, respectively. $v$ represents the propogation velocity of the travelling wave and $z_c$ is the wave impedance of the line. $x$ gives the distance from busbar, where fault occurs and t is the time at which fault occurs. Equations (1) and (2) which represent the transient voltage and current at any position along this line, are the superposition of forward travelling wave and backward travelling wave. The forward wave and backward wave can be obtained by solving equations (1) and (2) and is given as:

$$u^{+} = \frac{(\Delta u + z_c\Delta i)}{2} \quad ................(3)$$

$$u^{-} = \frac{(\Delta u - z_c\Delta i)}{2} \quad ...............(4)$$

## III. PROPOSED PROTECTION SCHEME

The proposed scheme is intended to operate as explained below. Consider there are ‘n’ transmission units connected to the same busbar, with ‘n’ relay units connected respectively. Each relay unit independently acquires current and voltage signals of the local bay itself, discriminates the fault direction, and sends the discrimination result. Any unit, in which there is a positive direction fault, will not issue a tripping command to the local breaker. If in one unit there is a negative direction fault and all other units have the same discrimination results, then it will immediately issue a command to trip the local circuit breaker (CB). In this case, an internal busbar fault has been verified, and all units will issue the trip command at once, so the faulted busbar is separated. For any other situations, all protection units must be kept stable.

### *A. Detection Algorithm*

According to the superposition theory, when a fault occurs, the post-fault voltage or current consists of two parts: the prefault steady-state component and the fault generated component. The second component can also be divided into two parts: the steady-state component and the transient component. This transient component is the so called travelling wave.

In this work, to make use of the transient components of broad frequency bandwidth, instead of using the wavefront amplitude of initial travelling wave, the waveforms of positive direction and negative direction travelling waves are integrated during a specific time of post-fault, respectively. According to the integral values of directional travelling waves, the criterion identifying the fault direction may be established.

For each line, defining the positive direction of the travelling wave is from the busbar to the line itself. Signals $S_1$ and $S_2$ which denote the sum of amplitudes of all detected positive and negative direction traveling waves, respectively, are as follows:

$$S_1 = \int_{t0}^{t0+\tau} |u^{+}(t)|dt \quad ..................(5)$$

$$S_2 = \int_{t0}^{t0+\tau} |u^{-}(t)|dt \quad ..................(6)$$

Where, $t_0$ is the instant that the initial travelling wave arrives at busbar and τ= min$\{\frac{2d_i}{v}\}$ for $d_i$ is the length of $l_i$.

To determine the fault direction conveniently, a ratio is defined as:

$$\lambda = \frac{s_1}{s_2} \quad .........................(7)$$

If ratio, λ is less than a threshold, $k_0$ (0< $k_0$<2) the fault direction is identified as positive. Otherwise, the fault direction is identified as negative. If the identified results from all lines are negative, then a busbar fault can be determined.

### i. Fault detection

Each protection unit independently acquires current and voltage signals of the local bay itself. These voltage and current signals are sampled at a high sampling rate, and then these sampled values are filtered to obtain the incremental components. For a three phase power system, the Clarke transform technique is applied to decouple the voltage and current signals, and further the extracted aerial mode components of voltage and current are used to form the directional travelling waves.

The first block, filter and A/D, performs the sampling of current and voltage signals and the high frequency transient components are obtained digital signals. These incremental components are then transformed into a static reference frame through clarke’s transform technique. The Clarke transform matrix is expressed as:

$$\begin{bmatrix}\alpha_0\\ \alpha_1\\ \alpha_2\end{bmatrix} = \frac{1}{3}\begin{bmatrix}1 & 1 & 1\\ 2 & -1 & -1\\ 0 & \sqrt{3} & \sqrt{3}\end{bmatrix} \begin{matrix}\beta_0\\ [\beta_1\ ]\\ \beta_2\end{matrix} \quad ......................(8)$$

where $\alpha_0$ is the zero mode component of voltage signal or current signal, $\alpha_1$ and $\alpha_2$ are the aerial mode components of voltage signal or current signal; $\beta_i$ is the phase voltage or phase current (i = a, b, c).

Then the waveforms of directional travelling waves are obtained from equations (3) and (4). The so obtained directional travelling waves are then integrated using equations (5) and (6), and their ratio is derived from equation (7). If the derived ratio is less than the threshold value, the fault direction is identified as positive. Otherwise, the fault direction is identified as negative. The results from each individual bay unit is then passed from the local relay through communication channels. If the identified results from all lines are negative, then a busbar fault can be determined.

ii. Fault location

Voltage signals from both transmission line ends are used to detect the first transient instants $t_{11}$ and $t_{21}$ , the line length and the propogation velocity of aerial modes are known, equation (8) is used to calculate the fault point location.

$$d = \frac{(l+(t_{11}-t_{21})v}{2} \qquad ..................(8)$$

Where $t_{11}$ is the initial transient instant at Bus 1, $t_{21}$ is the arrival instant of the reflected wave at Bus 1, d is the distance at which fault occurs, $l$ is the line length, $v$ is the velocity of travelling waves.

The orthogonal voltage phasors in static reference frame is obtained through Clarke's transformation. Park's transformation is applied to the output voltage signals of Clarke's transformation to obtain the voltage $v_d$, used to determine the fault location.

For high impedance fault cases, $v_d$ coefficients presents high attenuation. Thus, to increase the sensitivity of the proposed algorithm, difference coefficients ($c_{diff}$) are calculated using Taylor´s approximation:

$$c_{diff}(i) = \frac{v_d(i)-v_d(i-1)}{\Delta t} ..............(9)$$

Where, $v_d$ is the direct axis component, *i* is the sample number; $\Delta t$ is the time step.

In this work, ${c_{diff}}^2$ will be used to detect the initial transient instants in monitored terminals. ${c_{diff}}^2$ makes the transient detection more robust because coefficient related to transient signals are amplified and coefficients related to normal conditions of the system are kept with low magnitude.

In a two-terminals fault location method, ${c_{diff}}^2$ from both line ends must be calculated. The analysis of ${c_{diff}}^2$ coefficients allows the identification of the sample number in which occur initial transients. So, to use (8) to estimate the fault point, it is necessary to obtain the initial transient instants in seconds. ${c_{diff}}^2$ with magnitude below a given preset threshold are eliminated and so, coefficients related to noise and low frequency oscillation are ignored. Consequently, only ${c_{diff}}^2$ coefficients related to transients by the fault occurrence are considered.

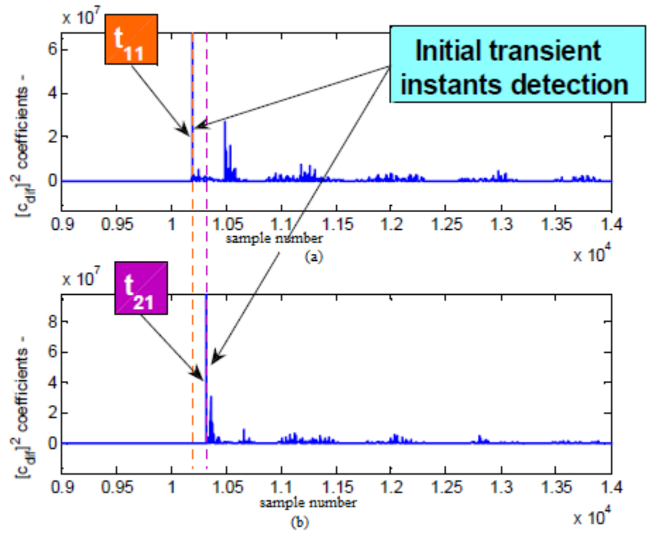



Fig. 2 ${c_{diff}}^2$ coefficients related to terminals 1 and 2

## III SIMULATION RESULTS

In order to verify the concept of the protection scheme discussed, a 230kV busbar test system is constructed.

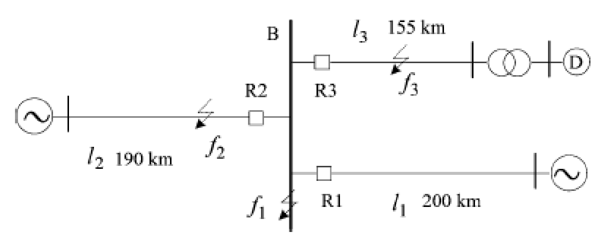



Fig. 3. Simulation model for the busbar structure

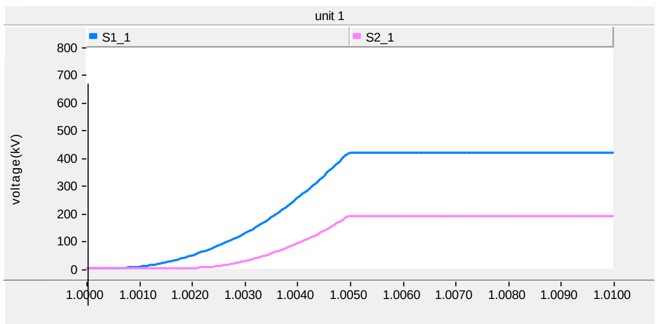
Fig. 2 shows the constructed 230 kV system in PSCAD/EMTDC, modelled as a simple power system represented by a single circuit, three phase transmission line with lumped parameter equivalent sources at each line end. A power network can have many possible system configurations. The main objective here was to select a more practical system configuration to identify the feasibility of the proposed protection scheme.

Considering various external fault occurring at $f_2$ in order to test the feasibility of proposed criterion. The simulation results are shown in Table I. It can be seen that the amplitudes of the positive direction travelling waves detected by units $R_1$ and $R_3$ are all greater than those of the negative direction travelling wave, but for unit $R_2$, the situation is just the opposite. According to the calculated ratio in Table I, an external fault can be determined. So the discrimination result is correct.

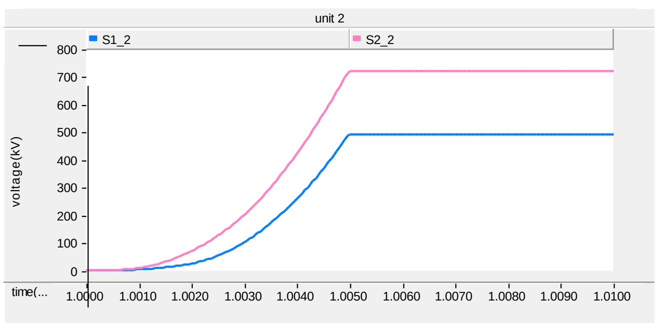
TABLE II

Fault Location Results for External Fault

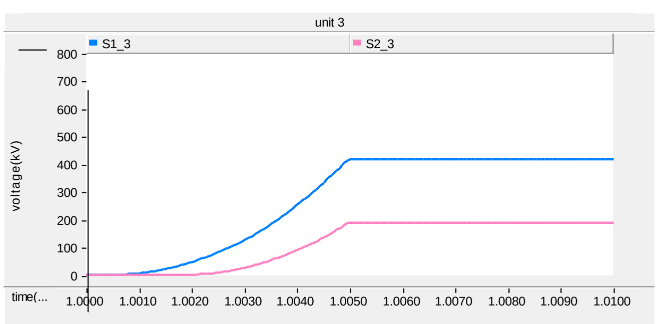
| *Protection unit* | $S_1(kV)$ | $S_2(kV)$ | $\lambda$ | *Fault Direction* | *Analysis* |
|---|---|---|---|---|---|
| $R_1$ | 417.1 | 188.9 | 2.207 | Negative | External |
| $R_2$ | 491.8 | 720 | .683 | Positive | External |
| $R_3$ | 417.1 | 188.9 | 2.207 | Negative | External |




(a)




(b)




(c)

Fig. 4. Detected Directional Travelling Waves for an External Fault at $f_2$

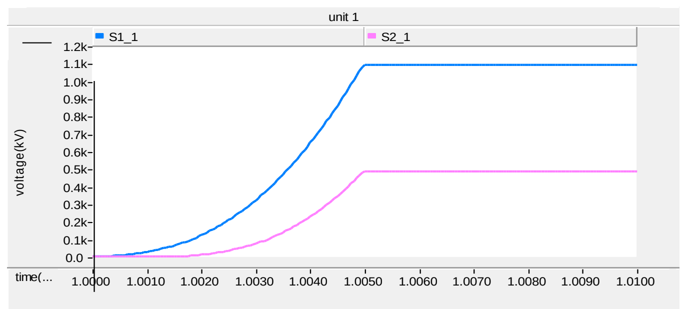
Regarding a three phase to ground fault occurring at $f_2$ away from busbar, figure 3(a)-(c) shows the detected directional travelling waves at unit 1,2 and 3 respectively

In Table II is shown a general analysis of the simulations for an internal fault, in which it can be seen that $\boldsymbol{S_1}$ is greater than $\boldsymbol{S_2}$ for any relay unit. Therefore, each protection unit determines that the fault direction is negative, which means this fault occurs on the busbar. So the discrimination result is correct.

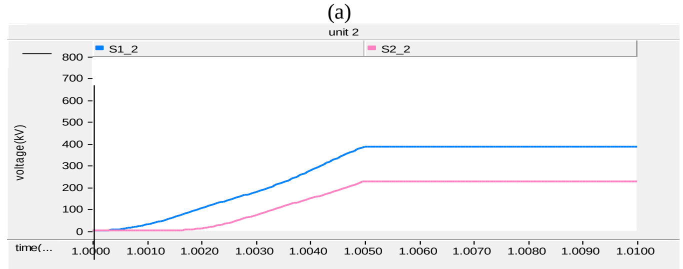
TABLE I

Fault Location Results for Internal Fault

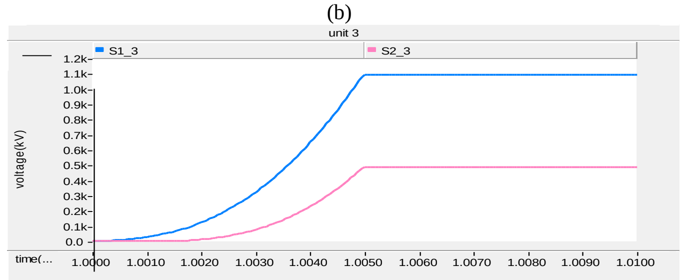
| *Protection unit* | $S_1(kV)$ | $S_2(kV)$ | $\lambda$ | *Fault Direction* | *Analysis* |
|---|---|---|---|---|---|
| $R_1$ | 1092.3 | 484.6 | 2.254 | Negative | Internal |
| $R_2$ | 382.4 | 225.4 | 1.696 | Negative | Internal |
| $R_3$ | 1092.5 | 484.7 | 2,254 | Negative | Internal |




(a)




(b)




(c)

Fig. 5. Detected Directional Travelling Waves for an Internal Fault at Busbar

## IV CONCLUSION

In this paper, an approach for fault location on power system analysed using travelling waves was presented. The travelling waves initiated by a fault depend not only on the fault position but also on the fault type, the fault inception angle, fault impedance and the power system configuration. These factors consequently have an influence on the reliability of the decision made by a travelling wave protection scheme. The first wavefront initiated by a fault that appears at the relay location contains information about the fault direction, fault type and fault inception angle. This initial information can be used to determine whether the travelling wave algorithm will be able to identify a disturbance and classify it as an internal or external fault. A 230kV busbar test system is developed using the simulation tool PSCAD/EMTDC. Different fault conditions are applied and corresponding waveforms are observed.

REFERENCES

[1] Badri Ram, D. N. Vishwakarma, "Power System Protection And Switchgear", Tata McGraw-Hill Education, 01-Apr-2001

[2] M. S. Sachdev, T. S. Sidhu, and H. S. Gill, "A busbar protection technique and its performance during CT saturation and CT ratio-mismatch," *IEEE Trans. Power Delivery, vol. 15, pp. 895–901, July 2000*

[3] M. M. Eissa, "A novel digital directional technique for bus-bars protection," *IEEE Transactions on Power Delivery,* vol. 19, no. 4, pp. 1636–1641, Oct. 2004.

[4] Chen Wei, Malik OP, Yin Xianggen, Chen Deshu, Zhang Zhe, "Study of wavelet based ultra high speed directional transmission line protection" , *IEEE Transactions on Power Delivery,* vol. 18(4), pp.1134–9, June 2003

[5] M. E. Mohammed, "High-speed differential busbar protection using wavelet-packet transform," in *Proc. Inst. Elect. Eng., Gen. Transm. Distrib.,* Nov. 2005, vol. 152, no. 6, pp. 927–933.

[6] Jafarian P, Sanaye-Pasand M, "A travelling-wave-based protection technique using wavelet/PCA analysis", *IEEE Transactions on Power Delivery* , vol.25(2), pp.588–99, April 2010

[7] C. Aguilera, E. Orduna, and G. Ratta, "Adaptive noncommunication protection based on traveling waves and impedance relay," *IEEE Transactions on Power Delivery,* vol. 21, no. 3, pp. 1154–1162, Jul. 2006.

[8] V. Lopes, D. Fernandes Jr and W. L. A. Neves, "Fault Location on Transmission Lines Based on Travelling Waves", *International Conference on Power Systems Transients* (IPST2011), Netherlands, June, 2011

[9] Guibin Zou,Houlei Gao ,"A traveling-wave- based amplitude integral busbar protection technique", *IEEE Transactions on Power Delivery,* vol. 27,no. 2, pp.602-609 Apr.2012